

PENETRATING WOUNDS OF THE BRAIN

AN EXPERIMENTAL STUDY

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THE extremely variable tolerance of the brain for foreign bodies introduced through penetrating wounds of the skull has led to a wide diversity of opinion regarding their treatment. Many cases of prolonged retention of foreign bodies without symptoms are on record. Elliot's¹¹⁰ patient was known to have had a bullet in his brain for 65 years without symptoms, and other cases have survived 30 years (Martin¹²¹), 27 years (Tanaka¹³³), 18 years (McLean²⁰⁴), piece of steel; Schlöss,¹⁷⁵ knife blade, 17 years; (McEachern²⁰³), surgical probe; and similar periods.

On the other hand, latent brain abscesses have made their appearance after 16 years (Urechia¹⁶⁵), 11 years (Bregman¹⁵⁵), 10 years (Ransohoff¹⁶⁴), and lesser intervals; and innumerable cases of late epilepsy are reported.

By far the most common foreign bodies lodged in the brain have been bullets and the voluminous literature of the various periods of war has abounded in reports and discussions on the subject. However, in less frequent instances the brain has been penetrated by almost every other conceivable instrument. Of these, knife blades are the most common (Babcock,¹⁶⁷ Blaine,¹⁶⁸ Brown and Birch,¹⁶⁹ Dretzka,¹⁷⁰ Guleke,¹⁷¹ Karschulin,¹⁷² Pepper,¹⁷³ Schloffer,¹⁷⁴ Schlöss,¹⁷⁵ Selwyn,¹⁷⁶ Slee,¹⁷⁷ Sommer,¹⁷⁸ Wilkins¹⁷⁹) and cases have been reported of penetration of the brain by pitchfork prongs (Kesteven,¹⁹⁸ Hooper¹⁹⁵), a crochet hook (Franklin¹⁹¹), a knitting needle (Annandale¹⁸¹), breech-pins (Cunningham,¹⁸⁵ Thompson,²¹¹ Kemper,¹⁹⁶ Burr,¹⁸⁴ Noyes²⁰⁵), surgical instruments (McLean,²⁰⁴ McEachern²⁰³), pieces of wood (Pridioux,²⁰⁷ Matthews,²⁰² Ferguson,¹⁸⁹ Key and McCrummen¹⁹⁹), the rib of an umbrella (Donkin¹⁸⁶), a crow-bar (Harlow^{194, 183}), iron rods (Swanson,²⁰⁹ Pugh²⁰⁸), nails (Levin,²⁰⁰ Felty¹⁸⁸), and other bizarre objects.

In the first half of the last century, most surgeons adhered to the conservative advice of Sir Benjamin Brodie¹⁴ (1828), who stated that no foreign body should be removed unless it lay on the surface of the brain in an already open wound. By the middle of the century, some surgeons had begun to remove foreign bodies in some instances. In the "Medical and Surgical History of the War of the Rebellion"⁸⁶ are reported 85 cases of bullet removal, of which 43 are listed as "recoveries." In 1868, Andrews³ reviewed 73 cases of retained bullet and advocated removal ("and the sooner the better") of all superficial foreign bodies which could be definitely located and easily approached. Ten years later, the same opinion was expressed by Wharton⁸⁸ who collected 316 cases. Of these, the foreign body was removed in 106 cases

with 72 recoveries and not removed in 210 cases with only 88 recoveries. Similar opinions were expressed by Morris⁵⁵ (1887), and Papaillon⁶¹ (1894). Hewett and Lidell⁴⁰ stated (1881): "Every reasonable effort should be made to extract foreign bodies when lodged in the brain."

With the discovery of roentgen rays (first employed for the location of cranial and intracranial foreign bodies in 1896 by Stubenbord²¹² of New York, Eulenberg²¹³ and Schier²¹⁴ of Berlin, and Fowler²¹⁵ of Brooklyn, in the order named), the removal of many more foreign bodies was attempted. Indeed, Phelps¹²⁶ wrote, "There is probably no authenticated case . . . in which the bullet left in the brain substance has failed to work mischief," and in 1910 Da Costa²¹ stated, "Practically every lodged bullet (in the brain) constitutes a fatal condition and it should be removed if possible, even if there are no symptoms."

With the beginning of the World War, another controversy further complicated the situation. Prior to this time, the commonly accepted method of treatment of penetrating wounds of the brain had consisted in removal of fractured bone, leaving the wound, including the dura mater, open, allowing a cerebral hernia to develop and the wound to heal (if it would) by secondary intention (von Bergmann,¹¹ Papaillon,⁶¹ Doyot²⁶). This method was advocated again during the war (Whitaker,⁸⁹ Moulouguet and Legraine,⁵⁶ Hunt⁴⁵), but was condemned by Bányi,^{8, 9} Cushing,^{18, 19, 20} Willems⁹⁰ and many others, who advocated early operation, complete débridement and primary suture.

The diversity of opinion continued throughout the war, both as regards foreign bodies and the open and closed methods of treatment. Gross and Houdard³⁴ advocated primary suture of wounds without removal of foreign bodies. Sargent and Holmes^{68, 69} stated that only readily accessible foreign bodies should be removed. On the other hand Dretzka,²⁵ Tilmann,⁷⁷ Mathieu,⁵³ Anderson¹ and others advised primary suture after removal of all foreign bodies. Moulouguet and Legraine⁵⁶ thought all foreign bodies should be removed and the wound left open. In 1918, Cushing^{19, 20} advanced the rational doctrine that foreign bodies should be removed whenever the damage of removal did not exceed the trauma of the original penetration. He devised the catheter-suction method of débridement and employed the "tripod" or "Isle-of-Man" incisions with primary suture in all cases. These principles were widely accepted (Horrax,⁴² Neuhoﬀ,⁵⁹ Harvey,³⁸ Willems⁹⁰).

Many special methods came to be employed. Localizing and extraction apparatus was designed by Hirtz,²⁴⁶ Ferguson,²⁴⁵ Banzet,²⁴⁴ and Swanberg,²⁴⁸ electromagnets were employed by Lee,²³⁸ Cords,²³⁴ Lefort,²³⁹ Cushing,²³⁵ Sargent and Holmes,²⁴² La Peyre,²³⁷ Mauclair,²⁴⁰ Spick and Jauréginberry,²⁴³ Kümmell²³⁶ and Regard,²⁴¹ and extraction under the fluoroscopic screen was advocated by Cazamian,²²⁷ La Peyre,²²⁹ Rouvillois,²³³ Lee²³⁰ and others.*

* In 1903, Holzknecht²²¹ anticipated the fluoroscope by making plate exposures at operation to determine the location of a previously inserted probe in relation to the foreign body.

De Martel⁵² was the first to advocate the use of local anesthesia, which was widely employed thereafter.

Concerning the late treatment of retained foreign bodies, it was generally agreed that only those which were very superficial or those which were causing symptoms should be removed (Bagley,⁹² Coleman,¹⁰³ Frazier and Ingham,¹¹² Demmer,¹⁰⁶ von Eiselsberg¹⁰⁹). This was finally expressed as the official opinion of the Interallied Surgical Conference.¹¹⁶

That the diversity of opinion alluded to above exists is ample evidence that the factors underlying the tolerance of the brain for foreign bodies are poorly understood. On only one of these factors is there unanimity of opinion: all observers agree that penetration of the cerebral ventricles by a foreign body greatly increases the danger of fatal infection (Harvey,¹⁴² Cushing,¹³⁸ Trotter and Wagstaffe,¹⁵² Regard,^{150, 151} Horrax¹⁴⁴ and others). Other factors, such as the duration of retention, and communication with the sub-arachnoid space or surface of the skin, have been generally ignored or disagreed upon.

Experimental work on the subject has been meager. In 1862, Flourens²⁵⁰ placed "leaden bullets" upon the surface of the brains of rabbits and dogs and observed that the presence of a foreign body seemed to predispose to "inflammatory action." In 1869, Philipeaux and Vulpian²⁵⁴ produced wounds in the left hemispheres of three dogs and observed that two died, while one recovered. Kramer and Horsley²⁵¹ studied the immediate effects of gunshot wounds on the circulation and respiration. Hortega and Penfield,²⁵⁵ and Penfield and Buckley,²⁵² have made careful studies of the histology of experimental cerebral wounds.

The present report is concerned with a study of some of the various factors influencing the outcome of penetrating wounds of the brain.

METHODS.—Dogs weighing from five to eight kilograms were used in all experiments. Experiments were of two general types: those in which a short, sharp nail about two millimeters in diameter was inserted through the skull to varying depths and left in place for varying lengths of time and those in which a lead air rifle shot (about two millimeters in diameter) was introduced into the brain through a small operative opening in the skull. In the former series, the animals were given morphia 0.13 Gm. (1½ gr.) one-half hour previously; in the latter they were anesthetized with ether.

The nails used were filed until very sharp and, with the animal's head firmly held on a wooden block, surprisingly little force was required to pierce the skull to any desired depth. Once through the skull, the nails were held firmly by the bone and could not be withdrawn without the use of a claw hammer or other instrument. After a period of two to four days, pressure necrosis (and, in some instances, infection) of the bone had occurred to a sufficient extent to render the nails loose and, in several instances, they came out spontaneously. In no instance was a fracture produced. Subsequent to the original procedure, all animals were observed frequently. In several

instances in which obviously fulminating infections developed and at the end of varying periods in surviving animals, they were painlessly sacrificed.

The same site was chosen in all animals for placing the nail or making the opening through which the shot was to be inserted. This was a point approximately 2 cm. above the posterior point of attachment of the left ear to the scalp. This point corresponds to a "silent" area of the brain and in no instance were any abnormal neurologic signs demonstrable immediately after the insertion of the foreign body.

Clinical neurologic signs are extremely difficult to evaluate in the dog. Only those which were quite definite will be mentioned in this report.

The nails and shot were not sterilized nor were they deliberately contaminated with any particular organism. Detailed bacteriologic studies were not made, but, in several instances in which cultures were made from widespread cerebral infections mixed growths of staphylococci, streptococci and *Bacillus coli* were obtained.

RESULTS.—*Group I.*—In 12 dogs, nails were inserted to a depth sufficiently great to penetrate the lateral ventricle and allowed to remain in place throughout the animals' lives. Approximately 1 cm. of the nail was left protruding from the scalp. The results are given in Table I.

TABLE I

The Effect of a Foreign Body Penetrating and Left Indefinitely in Communication with the Skin Surface

Dog No.	Duration of Life in Days	Ventricle Penetrated	Blood in Frontal Sinus	Postmortem Findings
N 1	2	Yes	Yes	Left ventricle distended with pus. Extensive left sided meningitis
N 2	2	Yes	Yes	Left ventricle distended with pus. Extensive left sided meningitis
N 3	2	Yes	Yes	Left ventricle distended with pus. Extensive left sided meningitis
N 4	1	Yes	No	Large hemorrhage in left ventricle. Clot in posterior fossa
N 5	2	Yes	Yes	Both lateral ventricles full of pus. Purulent meningitis on left
N 6	2	Yes	No	Pus-filled nail tract and ventricle on left. Left sided meningitis
N 7	14*	Yes	No	(1) Extensive osteomyelitis. (2) Dura adherent over left hemisphere. (3) Puncture wound sealed off. (4) Ventricular system distended pus
N 8	26†	Yes	No	Chronic healing meningitis; chronic inflammation and necrosis extending to ventricle and involving choroid plexus. Multiple microscopic abscesses in adjacent area

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TABLE I—*Continued*

N 9	6	Yes	Yes	Ventricular system full of pus. Widespread meningitis
N 10	3	No	No	Large left sided subdural abscess, extending to floor of middle fossa
N 11	3	Yes	No	Dura adherent at puncture site. Extensive ependymitis in lateral ventricles; gross pus in third and fourth ventricles and about brain stem
N 12	2	Yes	No	Adhesions over left hemisphere. Pus in left lateral, third and fourth ventricles and about the base; ependymitis in right lateral ventricle

* Nail came out spontaneously on sixth day. Animal died on fourteenth day.

† Nail came out spontaneously on fifth day. Animal sacrificed on twenty-sixth day.

One dog (N 4) died on the day on which the nail was inserted and was found to have a large intraventricular hemorrhage. Six dogs died on the second day, two on the third day and one on the sixth day after insertion of the nail. In eight of these nine animals, the nails were found to have penetrated the ventricles, and a widespread ventricular, cerebral, and meningeal infection was present. In six of these animals, the ventricles were distended with pus. In the ninth animal (N 10) who died on the third day, the nail had not penetrated the ventricle and the necropsy revealed a large subdural abscess.

Clinically, the signs in these nine animals were those of overwhelming infection and general impairment of the function of the central nervous system. Lethargy, rapidly progressing to stupor, coma and death, was present in all. Hemiplegia was apparently complete in Dog N 10 shortly before death. None of the animals had definite choking of the optic disks.

In one dog (N 7), the nail came out spontaneously on the sixth day. The animal ate well, was quite active and there were no apparent symptoms until the twelfth day when he became drowsy, refused food and grew rapidly worse. He died on the fourteenth day. During these two days, he developed high choking of the disks. At necropsy, the ventricular system was full of pus, but the puncture wound in the cortex was sealed off and apparently the outlet from the fourth ventricle was also obstructed, for no inflammation was found in the meninges.

In the single remaining experiment in this group (N 8), the animal was very ill for five days. He was apathetic, staggered and tended to fall to the right. The optic disks became hyperemic and their edges blurred. Pus exuded around the nail. On the fifth day, the nail came out spontaneously, and following this the dog slowly improved until, on the twenty-first day, he was entirely free of symptoms, ate well, and was quite active. The scalp wound had gradually ceased to discharge and was healed. The dog was sacrificed on the twenty-sixth day. Necropsy showed dense adhesions of the thickened dura and arachnoid and a walled off, chronically inflamed tract extending into the ventricle. Microscopically, the choroid plexus was found bound up in the chronic inflammatory process and there were numerous small adjacent abscesses, several of them containing fragments of bone. Compound granular corpuscles filled with phagocytized material were numerous and an area of gliosis extended well into the surrounding cerebral tissue.

In five of these dogs, there was terminal bleeding from the nose and at necropsy the frontal sinuses were found filled with blood. The cause of this is not clear and it is mentioned here as an incidental finding.

Comment.—It was apparent from these experiments that a number of factors might play a part in the development, severity and extent of the infections produced. Among these were the duration of retention of the foreign body, depth of penetration, and communication with skin, sub-arachnoid space and ventricle. Subsequent groups of experiments were designed to demonstrate the importance of these factors.

Group II.—In 12 dogs, nails were inserted as in Group I, but were removed at the end of 24 hours in four dogs, 12 hours in four dogs and immediately after insertion in the remaining four dogs. The results are given in Table II. In three of the four dogs retaining the nail for 24 hours, death occurred in four, two and three days, respectively. In two of these, the ventricle was penetrated, but in one of them (N 15), the infection found at necropsy did not involve the ventricle.

TABLE II

The Effect of a Deeply Penetrating Foreign Body Left in Communication with the Skin Surface for Twenty-four Hours or Less

Dog No.	Interval Before Removal of Nail, in Hours	Interval Before Death or Sacrifice, in Days	Spontaneous Death or Sacrifice	Ventricle Penetrated	Postmortem Findings
N 13	24	57	Sac.	No	Brain healed. Small cortical scar
N 14	24	4	Sp.d.	No	Small focus of cortical necrosis. No other cause of death found
N 15	24	2	Sp.d.	Yes	Large subdural abscess on left with inflammation in outer portion of nail tract
N 16	24	3	Sp.d.	Yes	Large cortical abscess with involvement of left ventricle
N 25	12	62	Sac.	Yes	Brain healed. Small cortical scar adherent to dura with tiny core extending to ventricle
N 26	12	62	Sac.	No	Brain healed. Superficial cortical scar
N 27	12	3	Sp.d.	Yes	Widespread purulent meningitis, and encephalitis. Left ventricle full of pus
N 28	12	81	Sac.	Yes	Brain healed. Scar tissue core extending to ventricle
N 17	0*	60	Sac.	Yes	Brain healed. Scar tissue core extending to ventricle
N 18	0*	102	Sac.	Yes	Brain healed. Scar tissue core extending to ventricle
N 19	0*	86	Sac.	No	Brain healed. Small cortical scar
N 20	0*	20	Sp.d.	Yes	Died of distemper. Brain healed

* In these animals, the nail was withdrawn immediately after its insertion.

In dog N 14, death occurred on the fourth day, but the necropsy revealed only a small focus of superficial cortical necrosis and the ventricle had not been penetrated.

Dog N 13 recovered and was sacrificed on the fifty-seventh day. The brain was healed and the ventricle had not been penetrated.

Three of the four dogs in whom the nails were left in place for only 12 hours recovered, and, when sacrificed after long intervals, showed no active intracranial infection. In two of the three, the ventricles had been penetrated. The remaining animal (N 27) died on the third day of a fulminating infection involving the ventricle.

All of the four dogs from whose brains the nails were removed immediately after insertion recovered without symptoms at any time and their brains were healed at necropsy. One of them died on the twentieth day of acute distemper. The ventricles had been penetrated in three of the four dogs.



FIG. 1.—Dog N 22. Well walled off abscess 21 days after penetration by foreign body.

Comment.—The experiments in this group showed clearly that the duration of retention of a foreign body communicating with the surface of the skin was a factor of prime importance and that, under these experimental conditions, the period of retention following which recovery was likely was not greater than 12 hours. Sargent⁶⁷ has stated that a delay of two to four days after receipt of the wound is advisable before operation is undertaken. The same opinion was concurred in by Cushing¹⁸ in 1916, but he later apparently believed in earlier operation.^{19, 20} Trotter and Wagstaffe⁸⁰ advocated extraction of foreign bodies within 12 hours if possible. The present experiments are in support of this opinion.

Group III.—In eight experiments, the foreign bodies were inserted as in the preceding groups except that the nails were shorter and the approximate depth of cortical

penetration was 6 to 10 Mm. in four dogs and 2 to 3 Mm. in four dogs. Table III shows the results. In seven of the experiments, the nail came out spontaneously in from two to eight days. Six of the eight animals recovered spontaneously and showed no active infection when sacrificed. One (N 22) died on the twenty-first day and necropsy showed a large, well localized cortical abscess (Fig. 1). The remaining dog (N 32) died of a fulminating infection on the second day. The infection involved the ventricle and it is possible that the latter was penetrated by the nail.

TABLE III

The Effect of a Superficially Penetrating Foreign Body Left in Communication with the Surface of the Skin. Ventricle Not Penetrated

Dog No.	Interval Before Spontaneous Loss of Nail, in Days	Interval Before Death or Sacrifice, in Days	Spontaneous Death or Sacrifice	Approximate Depth of Cortical Penetration, in Mm.	Postmortem Findings
N 21	4	44	Sac.	6-10	Adherent dura. Small cortical scar
N 22	8	21	Sp.d.	6-10	Large, localized cortical abscess. Local osteomyelitis
N 23	4	44	Sac.	6-10	Surface of brain red. Light dural adhesions. Cortical scar
N 24	5	44	Sac.	6-10	Small cortical scar
N 29	3	66	Sac.	2-3	No gross lesion in brain
N 30	4	66	Sac.	2-3	Tiny cortical scar
N 31	2	66	Sac.	2-3	Local dural adhesion to cortical scar
N 32	2	2	Sp.d.	2-3 (?)	Large subdural and cerebral abscess extending into left ventricle

Comment.—It is to be noted that the foreign bodies were retained in all the experiments in this group well beyond the period of safety found in animals whose ventricles had been penetrated (Groups I and II). It is apparent, therefore, that penetration of the ventricle greatly increases the danger of a fatal outcome in such wounds. This is in accord with the clinical opinions already cited.

Group IV.—In eight experiments, the scalp was closed over the nail. In four of them, the head of the nail was left outside the temporal muscle and just beneath the scalp (Table IV). Three of these dogs died of extensive purulent meningitis with cortical infection in three, six and five days, respectively. One of these (N 32) had a large cortical abscess (Fig. 2). In all these, there was purulent exudate and necrosis in the overlying muscle. The fourth dog recovered and at necropsy on the thirty-second day only a small subdural hematoma without meningeal or cortical infection was found. The muscle was densely adherent and fibrosed but was healed.

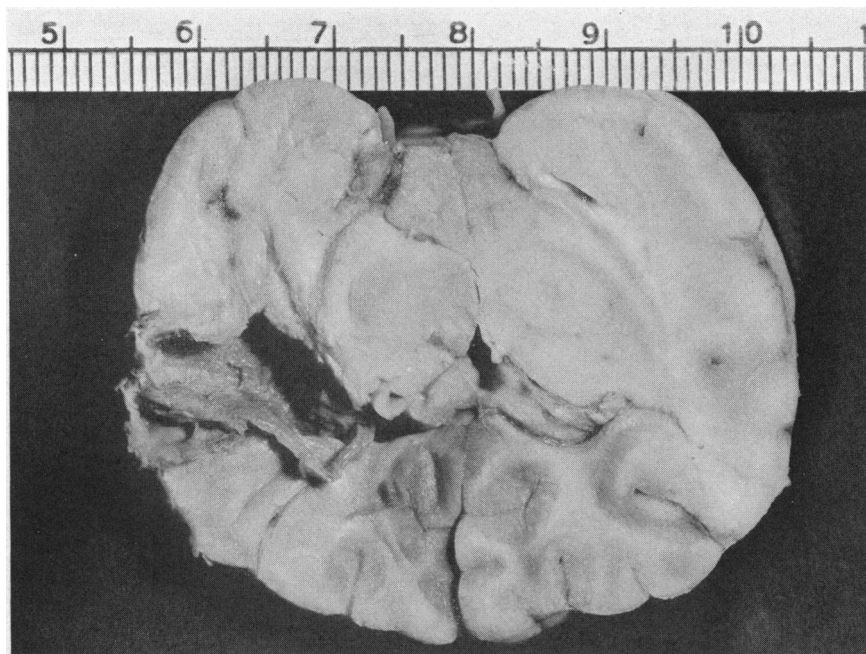


FIG. 2.—Dog N 36. Large necrosing cortical abscess five days after penetration by foreign body.

TABLE IV

The Effect of a Penetrating Foreign Body Over Which the Scalp Has Been Closed

Dog No.	Interval Before Death or Sacrifice, in Days	Spontaneous Death or Sacrifice	Postmortem Findings	Length and Depth of Nail
N 33	3	Sp.d.	Extensive purulent meningitis. Small, shallow cortical abscess	Nail, 1.5 cm long, with head inserted to outer surface of skull
N 34	32	Sac.	Chronic subdural hematoma. No apparent infection about nail	
N 35	6	Sp.d.	Purulent meningitis. Small localized cortical abscess	
N 36	5	Sp.d.	Purulent meningitis. Large localized cortical abscess	
N 37	2	Sp.d.	Small cortical abscess. No gross meningitis	Headless nail inserted through bone
N 38	37	Sp.d.	Well walled off subdural and cortical abscesses	
N 39	74	Sac.	Brain firmly healed about nail. Tip in ventricle	
N 40	74	Sac.	Brain firmly healed about nail	

In the other four dogs, the nails were headless and were inserted completely through the skulls by means of a steel pin with which they were driven. Dog N 37 died on the second day. Necropsy revealed only a small cortical abscess. Dog N 38 died on the thirty-seventh day with a large, well walled off subdural and cortical abscess (Fig. 3A). The other two dogs recovered completely. There was no infection about the nails, although in one of them (N 39) the tip of the nail had penetrated the ventricle (Fig. 3B). The muscle was completely healed in all except N 37. In the three animals in this group who recovered, the nails were completely isolated from the free subarachnoid space by dense dural adhesions.

Comment.—These experiments suggest that communication of a penetrating foreign body with the subarachnoid space considerably increases the danger of fatal infection and that this danger is further augmented if the foreign

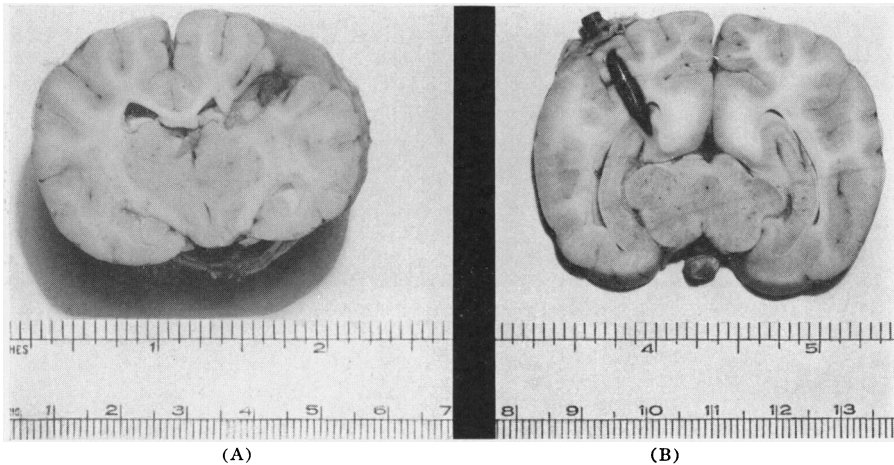


FIG. 3.—Headless nails were inserted into the cortex. (A) Dog N 38.—Large subdural and small cortical abscess, thirty-seventh day. (B) Dog N 39.—The brain is healed about the nail. The tip of the nail has penetrated the ventricle, seventy-fourth day.

body protrudes into the soft tissues overlying the skull. Angerer,⁴ in 1914, stated that all patients with wounds penetrating the dura died. This statement is somewhat extravagant, but the danger of communication of foreign bodies with the subarachnoid space has not been generally recognized.

Group V.—In each of eight dogs, an air rifle shot was inserted into the brain through an operative opening in the skull. The operations were performed under aseptic conditions except that no attempt was made to sterilize the shot which were picked up with a fine sterile forceps and inserted into the cortex to the desired depth. The wounds were closed in layers with silk.

In four experiments the shot were inserted to a depth of approximately 10 to 15 Mm. (Table V). All four animals recovered without having developed symptoms at any time. At necropsy, the shot were found firmly bound about with dense fibrous adhesions from which a scar tissue "core" as described by Penfield and Buckley²² led to the cortical surface (Fig. 4). The ventricle had not been entered in any case.

In the other four experiments, the shot were inserted to a depth of 20 to 30 Mm. Dogs N 52 and N 54 were sacrificed when severe symptoms appeared on the sixth and twentieth days, respectively. In both, the shot had traversed the ventricle and lay deep in the base of the brain. The inflammatory reactions in both were of a chronic nature with organization and fibrosis (Fig. 5). Both showed a low grade basilar meningitis.

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TABLE V

The Effect of the Penetration of a Non-protruding Foreign Body Into the Brain

Dog No.	Depth to Which Shot Was Inserted, in Mm.	Period Before Sacrifice, in Days	Postmortem Findings
N 41	10-15	106	Shot embedded in scar with core leading to cortex
N 42	10-15	85	Shot embedded in scar with core leading to cortex
N 43	10-15	254 plus	Still living
N 44	10-15	128	Shot embedded in brain. Thin core leading to cortex
N 51	20-30	50	Scar tissue core marks tract of shot
N 52	20-30	6*	Hemorrhagic, organizing abscess. Mild basilar meningitis
N 53	20-30	92 plus	Still living
N 54	20-30	20*	Small, superficial cortical abscess; tract about shot healing; fibrinopurulent exudate at base

* These animals were sacrificed when severe symptoms appeared.

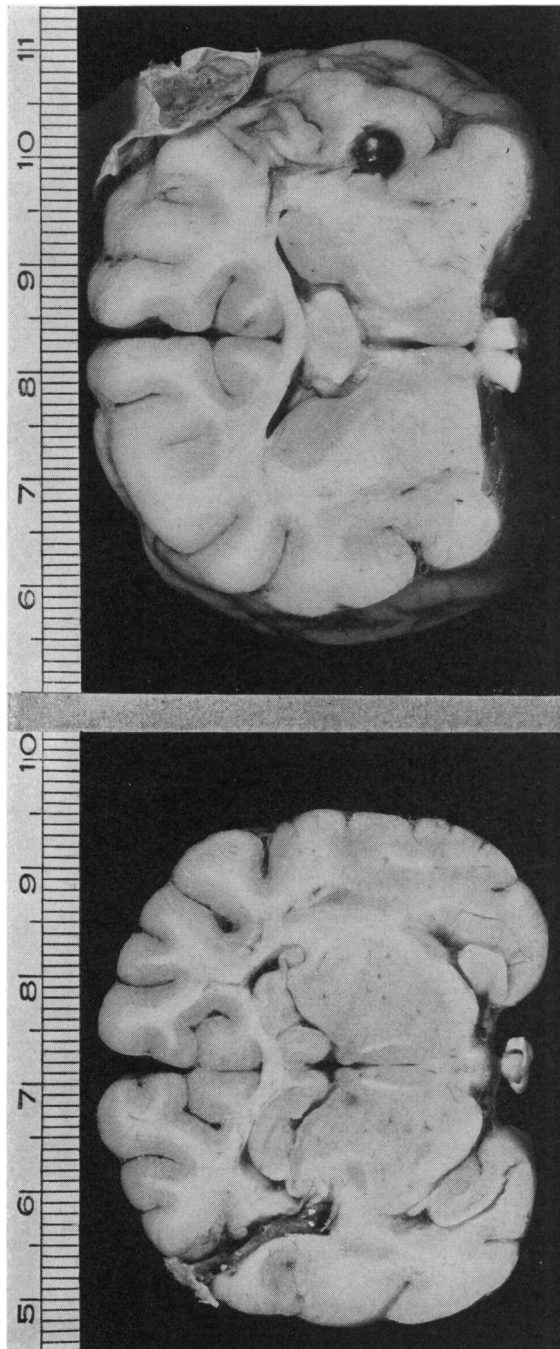
Dogs N 51 and N 53 recovered completely. In the former, the shot was found at the bottom of a healed tract, as in the previous group. Dogs N 43 and N 53 have been preserved alive for histologic study of a more long standing healing process.

Comment.—The uniform recoveries in the first four experiments of this group constitute strong evidence that the high incidence of fatal infection found in the preceding groups was the result of continuous communication of the foreign body with the skin surface, the ventricle or the subarachnoid space. This is substantiated by the development of infections (though less severe than in previous groups) in two of the four animals in which the ventricle was traversed by the shot. This does not necessarily imply a greater intrinsic resistance to infection on the part of the cerebral tissue, but rather suggests that the greater danger of contamination of the ventricles or subarachnoid space arises from the rapid spread of the infection by means of the cerebrospinal fluid. This is borne out by the findings in dog N 7 (Group I) who survived 14 days with an extensive intraventricular infection which was sealed off from the adjacent cerebrospinal fluid spaces.

Group VI.—In six dogs, nails were inserted into the brain to a depth of approximately 10 Mm. (as in Group III). After varying intervals, under ether anesthesia and with aseptic precautions, the nails and surrounding area of bone (about 2 cm. in diameter) were removed and the dura widely opened. The wounds were then packed open. The results are given in Table VI.

In the first two dogs, the operation was performed two days and in the third three days after insertion of the nail. Active infection was found in two of these three animals. All three made complete recoveries after operation. The wounds drained freely at first, then gradually filled with granulations and healed. N 45 and N 46 were completely healed on the fifteenth day and N 47 on the nineteenth day after operation.

In the remaining three animals, operation was performed five days after insertion of the nail in N 48 and seven days in N 49 and N 50. Dog N 48 died the day follow-



(A) (B)
FIG. 4.—Embedded shot with healed “cores.” The ventricles have not been penetrated.
(A) Dog N 42, eighty-fifth day. (B) Dog N 41, one hundred and sixth day.

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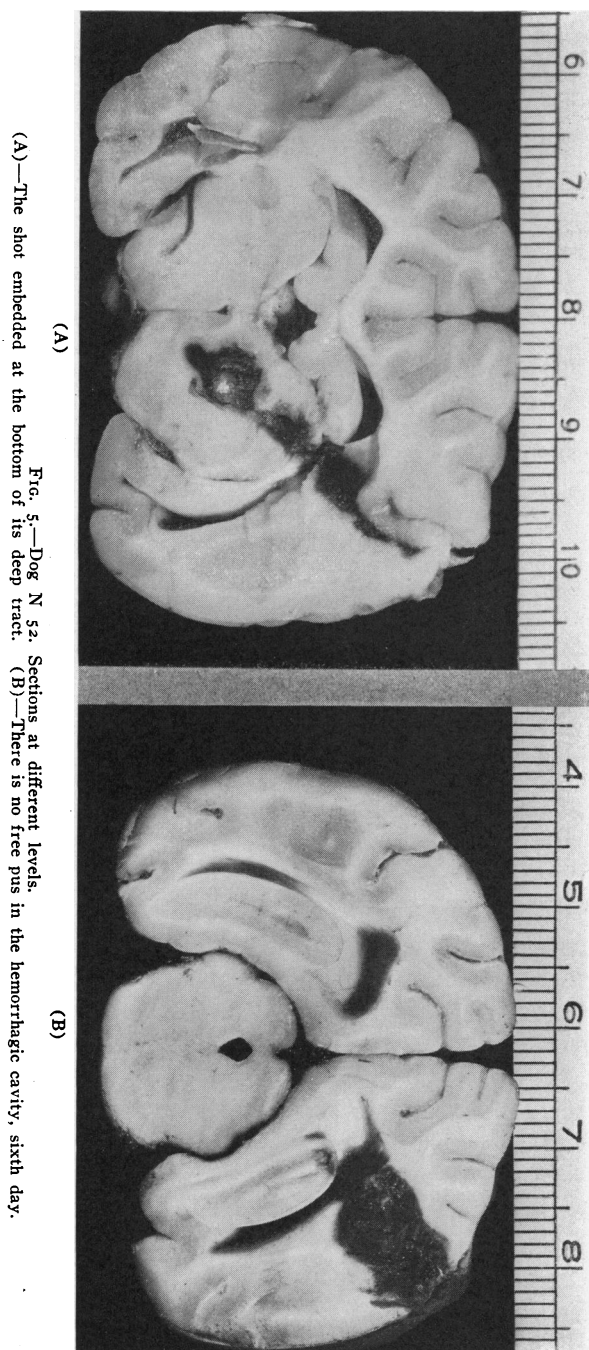


FIG. 5.—Dog N 52. Sections at different levels. (A)—The shot embedded at the bottom of its deep tract. (B)—There is no free pus in the hemorrhagic cavity, sixth day.

TABLE VI

The Effect of the Operative Removal of a Penetrating Protruding Foreign Body with Its Surrounding Area of Bone and Dura Mater. Wound Left Open

Dog No.	Interval Between Insertion of Nail and Operation, in Days	Operative Findings	Postoperative Period, in Days	Spontaneous Death or Sacrifice	Postmortem Findings
N 45	2	No gross infection	84	Sac.	Brain healed. Adhesions. Cortical scar
N 46	2	Small amount of subdural pus	169 plus	—	Still living
N 47	3	Small amount of subdural pus	65	Sac.	Small cortical scar. Dural adhesions
N 48	5	Small amount of subdural pus	1	Sp.d.	Localized cerebral abscess
N 49	7	Cortical granulations. No pus	14	Sp.d.	Walled off subdural abscess
N 50	7	Extensive purulent meningitis	0*	Sp.d.	Extensive meningitis and encephalitis extending into ventricle

* Animal died as anesthetic was begun.

ing operation and was found to have a large localized cerebral abscess. Dog N 50 died as the anesthetic was begun. Hasty removal of the nail with release of pus under great tension failed to resuscitate him. At operation dog N 49 was found to have no actual purulent exudate, but definite evidence of infection. The wound drained profusely and the animal was free of symptoms until the twelfth day after operation. On this day, he was listless and drowsy, refused food and water and looked ill. All extremities were moved well and the reflexes were normal. The following day, high choking of the optic disks was observed. Drainage had greatly diminished. On the fourteenth day the animal died. Necropsy revealed that the infection had become walled off to form a large subdural abscess.

Comment.—These experiments demonstrate that the increase in likelihood of recovery resulting from removal of a protruding foreign body may be augmented by ensuring adequate drainage, providing subdural or cortical infection is already established.

SUMMARY AND CONCLUSIONS

The effects of penetrating wounds of the brain by protruding foreign bodies and by deeply embedded foreign bodies have been studied in 54 dogs. The foreign bodies were unsterile and were inserted to varying depths and left in place for varying periods of time.

Foreign bodies penetrating the ventricle and allowed to remain protruding through the skin invariably produced a fulminating, fatal infection of meninges, brain and ependyma.

Removal of the protruding foreign body within 12 hours after its insertion greatly reduced the incidence of fatal infection.

Failure to penetrate the ventricle by a protruding foreign body considerably reduced the incidence of fatal infection.

Closure of the scalp over the inserted foreign body reduced the incidence of fatal infection and prolonged the survival time if infection developed.

Deeply embedded foreign bodies which did not communicate with the skin or subarachnoid space did not cause fatal infection unless the ventricle had been traversed.

In the presence of established superficial cerebral infection about protruding foreign bodies, early adequate drainage greatly reduced the mortality rate.

The following therapeutic suggestions may be made:

(1) Foreign bodies in the brain which are in communication with the skin, the subarachnoid space or the ventricular system should be removed at the earliest possible moment.

(2) Deeply embedded foreign bodies not falling in the category just mentioned should be removed only if focal irritation or destructive symptoms are present.

(3) If infection already exists about a superficially placed or protruding foreign body, its removal should be accompanied by the establishment of adequate open drainage.

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